ENERGYSOLUTIONS

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Internal Dose Assessments

Revision 0

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Table of Contents

1.0 PURPOSE AND SCOPE

Bioassay(s) are performed to ensure that significant intakes have not occurred and to provide the necessary data to perform a dose assessment in the event a positive result is observed. This procedure specifies the techniques used for the evaluation and investigation of personnel dose based upon analytical results obtained from in-vivo or in-vitro bioassay monitoring. In the event that any bioassay results are determined to be above the administrative action levels or when the results may indicate a potential discrepancy within the radiation protection program for which the personnel monitoring results do not make sense (i.e., discrepancy with anticipated levels of exposure or ALARA estimates), an investigation report should be performed following the guidance of this procedure.

It should be noted that this procedure only applies to positive internal monitoring results as negative results do not require an internal dose assessment. Negative bioassay results show the absence of any significant internal exposure and demonstrate the effectiveness of the radiation protection program provided the analytical sensitivities are adequate.

Internal monitoring via bioassay is the preferred method for measuring the intake of radionuclides; however, internal dose assessments may also be performed via DAC-hr tracking and is covered under separate procedure. DAC-hr tracking should be used in the event that bioassay monitoring is not sensitive enough.

Note: The DOE requires, in 10CFR835.209(b), that the estimation of internal dose shall be based on bioassay data rather than air concentration values unless bioassay data are: (1) unavailable; (2) inadequate; or (3) internal dose estimates based on air concentration values (i.e., DAC-hr tracking) are demonstrated to be as or more accurate.

1.1 Purpose

The purpose of this procedure is to provide specific guidance for the dose assessment for the intake of radionuclides based upon in-vivo and in-vitro bioassay monitoring. Any calculated doses greater than 10 mrem **should** be included with the workers exposure record; however, all calculated doses greater than 100 mrem TEDE or 100 mrem to any individual organ or tissue **shall** be reported as part of the individual annual exposure record in accordance with 10CFR19.13, *Notification and reports to individuals*.

This procedure follows the regulatory requirements and guidance as contained in 10CFR20 and the US NRC guidance documents and is intended only as guidance. The actual calculation approach of a particular internal dose assessment will be specific to the exposure conditions and personnel monitoring methods. ANSI HPS N13.39, summarizes this approach by noting:

> *"It is not essential that pre-selected models be used for all cases; rather, a scientific approach is preferred for modeling the intake, retention, translocation, clearance, and excretion of radionuclides based on careful analysis of the data and characteristics of the internally deposited radionuclides."*

The approach for assessing internal exposure involves two steps. First, the estimated quantity of intake must be determined in μCi or Bq from available data, either through bioassay monitoring or DAC-hour tracking. This is typically determined using one of the following depending upon the radionuclides of concern, detection sensitivities, chemical form and class of radionuclide:

- Direct measurement of radionuclides in the body (in-vivo),
- Measurement of radionuclides in excreta (in-vitro), or
- Measurement of radionuclide concentrations in air combined with personnel residence times (i.e., DAC-Hour tracking).

Once the intake amount is determined, the persons exposure is estimated as dose equivalent to the whole body (i.e., Committed Effective Dose Equivalent or CEDE) and/or a dose to a specific organ or tissue (i.e., Committed Dose Equivalent) through the use of available conversion factors such as those provided in Federal Guidance Report 11 for bioassay monitoring or through the use of the Annual Limit on Intake (ALI).

1.2 Scope

This procedure is for the exclusive use of Energy*Solutions* Commercial Services Division and contractors at field project sites where Energy*Solutions* has the primary role in controlling exposures to on-site personnel. Requirements herein are applicable to no other operational entities of Energy*Solutions*.

2.0 REFERENCES

2.1 US NRC 10CFR19, *Notices, instructions and reports to workers: inspection and investigation*

2.2 US NRC 10CFR20, *Standards for protection against radiation*

2.3 US DOE 10CFR835, *Occupational radiation protection*

2.4 US NRC Regulatory Guide 8.7, *Instructions for Recording and Reporting Occupational Radiation Dose Data, 2005*

2.5 US NRC Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program, Revision 1, 1993*

2.6 US NRC Regulatory Guide 8.34, *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses, July 1992*

2.7 ANSI HPS N13.42, *Internal Dosimetry for Mixed Fission and Activation Products, 1997*

2.8 NUREG/CR-4884, *Interpretation of Bioassay Measurements, 1988*

2.9 NUREG/CR-5631, *Contribution of Maternal Radionuclide Burdens to Prenatal Radiation Doses*

2.10 ICRP 23, *Report of the Task Group on Reference Man*

2.11 ICRP 30, *Limits for Intakes of Radionuclides by Workers*

2.12 ICRP 54, *Individual Monitoring for Intake of Radionuclides by Workers: Design and Interpretation*

2.13 ICRP 68, *Dose Coefficients for Intakes of Radionuclides by Workers*

2.14 EPA 520/1-88-020 (Federal Guidance Report No. 11), *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*

2.15 Health Physics, November 2002, Volume 83, Number 5, *Intake Retention Fractions Developed from Models Used in the Determination of Dose Coefficients Developed for ICRP Publication 68 – Particulate Inhalation*, Charles A. Potter

2.16 CS-RS-PG-001, *Radiation Protection Program Commercial Services Projects*

2.17 CS-RS-PG-002, *Respiratory Protection Program for Radionuclides – Commercial Services Projects*

2.18 CS-RS-PR-010, *Personnel Monitoring for Exposure – Internal and External*

2.19 ES-RS-PG-001, *Radiation Safety Program*

3.0 GENERAL

3.1 Definitions

3.1.1. *Annual Limit on Intake (ALI)* – The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a committed effective dose equivalent of 5 rem (0.05 Sv) or a committed dose equivalent of 50 rem (0.5 Sv) to any individual organ or tissue. ALI values for intake by ingestion and by inhalation of selected radionuclides are given in Table 1, Columns 1 and 2, of appendix B to 10CFR20.

3.1.2. *Bioassay (radiobioassay)* – The determination of kinds, quantities or concentrations, and, in some cases, the locations of radioactive material in the human body, whether by direct measurement (in-vivo counting) or by analysis and evaluation of materials excreted or removed from the human body (in-vitro counting).

3.1.3. *Class (or lung class or inhalation class)* – A classification scheme for inhaled material according to its rate of clearance from the pulmonary region of the lung. Materials are classified as D, W, or Y, which applies to a range of clearance half-times: for Class D (Days) of less than 10 days, for Class W (Weeks) from 10 to 100 days, and for Class Y (Years) of greater than 100 days.

3.1.4. *Committed Dose Equivalent (HT,50, or CDE)* – The dose equivalent to organs or tissues or reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

3.1.5. *Committed Effective Dose Equivalent (HE,50, or CEDE)* – The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues (HE,50 = ΣWTHT,50).

3.1.6. *Derived Air Concentration (DAC)* – The concentration of a given radionuclide in air which, if breathed by the reference man for a working year of 2,000 hours under conditions of light work (inhalation rate of 1.2 cubic meters of air per hour), results in an intake of one ALI. DAC values are given in Table 1, Column 3, of appendix B to 10CFR20.

3.1.7. *Derived Air Concentration-hour (DAC-hour)* – The product of the concentration of radioactive material in air (expressed as a fraction or multiple of the derived air concentration for each radionuclice) and athe time of exposure to that radionuclide, in hours. A licensee may take 2,000 DAC-hrs to represent one ALI, equivalent to a committed effective dose equivalent (CDED) of 5 rem (0.05 Sv) or a committed dose equivalent (CDE) of 50 rem (0.50 Sv) depending on the basis for the ALI.

3.1.8. *Dose Equivalent (HT)* – The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv).

3.1.9. *Effective Dose Equivalent (HE)* – The sum of the products of the dose equivalent to the organ or tissue (HT) and the weighting factors (WT) applicable to each of the body organs or tissues that are irradiated (HE = ΣWTHT).

3.1.10. *Embryo/fetus* – The developing human organism from conception until the time of birth.

3.1.11. *Exposure* – Being exposed to ionizing radiation or to radioactive material.

3.1.12. *Individual Monitoring* – (1) The assessment of dose equivalent by the use of devices designed to be worn by an individual; (2) The assessment of committed effective dose equivalent by bioassay (see Bioassay) or by determination of the time-weighted air concentrations to which an individual has been exposure, i.e., DAC-hours; or (3) The assessment of dose equivalent by the use of survey data.

3.1.13. *Intake Retention Fraction (IRF)* – The fraction of the original intake remaining in or retained by the body at time t following the time of intake.

3.1.14. *Internal Dose* – that portion of the dose equivalent received from radioactive material taken into the body.

3.1.15. *Nonstochastic Effect* – Health effects, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect (also called a deterministic effect).

3.1.16. *Stochastic Effects* – Health effects that occur randomly and for which the probability of the effect occurring, rather than the severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

3.1.17. *Total Effective Dose Equivalent (TEDE)* – The sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

3.2 Responsibilities

Note: Depending upon personnel qualifications and the size of the project, project personnel may be assigned multiple roles and/or responsibilities.

3.2.1. Commercial Services Radiation Safety Officer

The Commercial Services Radiation Safety Officer (CS RSO) maintains and oversees the implementation of the CS Radiation Protection and Respiratory Protection Programs. The CS RSO shall ensure that radiation safety, radioactive materials management, and radiological operations procedures and programs are kept up to date such that they comply with current regulations and incorporate current and relevant industry practices and regulatory guidance. The CS RSO shall assist the PHP in providing guidance on the proper personnel monitoring requirement and techniques and will review and approve all Internal Dose Assessments that are performed under Commercial Services projects.

3.2.2. Project Manager

The Project Manager (PM) is responsible for ensuring that the proper procedures and programs are implemented on the project site as required by customer agreements and contracts. The PM is responsible for ensuring that these programs and procedures are properly incorporated into project specific plans and procedures. The PM is responsible for ensuring that Commercial Services and/or client programs and procedures are available for use by field personnel. The PM shall also ensure that individuals provide bioassays as required.

3.2.3. Project Health Physicist

The Project Health Physicist (PHP) is responsible for assisting the CS RSO in providing health physics support to the PM and Radiation Protection Supervisor (RPS). This includes technical support to ensure procedural and regulatory compliance and to ensure that the project specific Data Quality Objectives are met. The PHP is responsible for specifying and verifying MDAs for the analysis laboratory, reviewing laboratory analysis data, evaluating the need for additional (special) bioassays and communicating and obtaining agreement from the CS RSO.

3.2.4. Radiation Protection Supervisor

The Radiation Protection Supervisor (RPS) is responsible for implementing the CS Radiation Protection and Respiratory Protection Programs and the project specific radiological requirements at the field project location. The RPS manages and oversees the project personnel in regards to radiation and respiratory protection and reports directly to both the PM and the CS RSO. The RPS shall in conjunction with the PM and the PHP, ensure that all personnel have followed the recommendations for internal monitoring including the issue and collection of bioassay kits as necessary.

3.2.5. Respiratory Protection Wearer

Project personnel are responsible for complying with the requirements of the Radiation Protection and Respiratory Protection programs and the implementing procedures. They are responsible for submitting to bioassay monitoring as required.

3.3 Precautions and Limitations

3.3.1. All internal dose assessment protocols as required by Energy*Solutions* for monitoring personnel exposures on project sites shall be approved by a Certified Health Physicist (CHP).

3.3.2. An internal dose calculation shall be performed by a CHP for all positive bioassay results. Any significant dose (i.e., 10 mrem or more) should be added to the individual's dose record; however all doses in excess of 100 mrem shall be recorded.

3.3.3. If a project is being conducted for the Department of Energy, the applicable regulations should be consulted. The DOE has adopted, in 10CFR835, newer exposure models for the derived secondary standards, annual limits on intake and derived air concentrations. The newer models impact primarily the thorium radionuclides raising the ALI and the DAC by a factor of 7 to 30.

3.3.4. For the intake of inferred radionuclides, use the calculated intake of the measured radionuclide. DO NOT use the measured bioassay activity for scaling other radionuclides.

3.4 Records

Note: In many cases, the Internal Dose Assessments as attached may not provide enough room or detail to properly document the exposure evaluation. A separate calculation using spreadsheets showing the assumptions, basis, calculation methods, and results is acceptable in lieu of the forms in this procedure.

3.4.1. Internal Dose Assessment

3.4.2. Records of Bioassay Results

3.4.3. Internal Exposure Investigation Reports

4.0 REQUIREMENTS AND GUIDANCE

4.1 Intake Evaluation – Data

In order to properly evaluate personnel exposure due to an intake of radionuclides, specific information is required in order to properly evaluate the potential exposure.

4.1.1. Determine the likely exposure scenario or intake model based upon the type of monitoring, the work evolutions being performed, air sampling results, etc. The potential exposure scenarios include:

- Single Acute Intake,
- Multiple Acute Intake, and
- Continuous Intake

4.1.2. As a minimum, determine the following information as applicable as it is required to perform the dose assessment:

- Date and time of the intake for single and multiple acute intakes,
- Monitoring period for continuous intakes,
- Personnel Protection Equipment and controls being implemented,
- Likely exposure pathway(s) (e.g., Inhalation vs. ingestion),
- Radionuclides of concern and their relative fractions,
- Bioassay results,
- Air monitoring data and RWP entry logs (i.e., DAC-hr tracking),
- Pulmonary clearance class of compounds (as applicable),
- Measurement system error and detection sensitivities.

4.1.3. Provide the necessary information to the PHP in order to fill out the intake information on the appropriate dose assessment form, Attachments 5.1, 5.2 or 5.3 for the appropriate exposure scenario, in order to complete the dose assessment.

4.2 Single Acute Intake

4.2.1. Complete the Dose Assessment, Attachment 5.1 or equivalent.

4.2.2. Record the individual's name and personal information as required.

4.2.3. Record the date and time that the bioassay was obtained (i.e., completed).

4.2.4. Record the best estimate of the date and time of the intake. The date and time may be estimated using available information including the RWP access logs, estimates based upon the recollection of activities, the individual's work schedule, air sampling data and operational history.

Note: If the information is insufficient to determine the time of intake, it is acceptable to assume the intake occurred at the

mid-point for the time period since the last bioassay measurement, their hire date or potential first date of exposure from the current bioassay sampling date.

It is also acceptable to conservatively assume the intake occurred immediately following the previous bioassay measurement, hire date or potential first date of exposure.

4.2.5. Calculate and record the time, *t*, in days between the estimated time of the event or intake and the time that the bioassay was obtained.

4.2.6. Record the radionuclide(s) of concern. Include those radionuclides that were detected through bioassay as well as those that can only be inferred based upon the radionuclide distribution and process knowledge.

4.2.7. Enter the inhalation class of the radionuclide(s) of concern based upon the chemical form as specified by the PHP/CHP and/or CS RSO. If the chemical form or inhalation class is not known, use the most restrictive class for the radionuclide.

4.2.8. Enter the total activity, $A_{i\text{-}Bio}$, from the whole body count or the bioassay sample measurement.

4.2.8.1. For urine samples reported in μCi/ml or pCi/ml, multiply the reported result by the actual 24-hr void volume or the "reference man" daily void (1,400 ml per day for men or 1,000 ml per day for women).

4.2.8.2. For fecal samples reported in μCi/g or pCi/g, multiply the reported results by the actual 24-hr weight of excretion, or the "reference man" daily excretion weight (135 g per day for men or 100 g per day for women).

4.2.9. If the bioassay results are believed to be from multiple acute or continuous intake or a combination of residual excretion from a previous intake plus a new intake, a separate evaluation should be performed in accordance with Sections 4.3, Multiple Acute Intake or 4.4 Continuous Intake as applicable.

4.2.10. Enter the Intake Retention Fraction, IRF_i, for each radionuclide present corresponding to the type of bioassay measurement (e.g., urine, fecal, whole body count, etc) for time *t* as determined in Step 4.2.5.

Note: The IRF values may be taken from Reference 2.8, NUREG/CR-4884, *Interpretation of Bioassay Measurements, 1988.* If interpolation between values is required use the logarithmic interpolation method as described in Reference 2.8 or Reference 2.5, US NRC Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program, Revision 1, 1993.*

4.2.11. Determine the intake using the following equation by dividing the total activity in the bioassay sample by the appropriate Intake Retention Fraction and enter the result on Attachment 5.1.

$$I_i = \frac{A_{i-Bio}}{IRF_i(t)}$$

Where: I_i = Estimated total intake in μCi, or Bq for radionuclide *i*

$A_{i\text{-}Bio}$ = Total activity for radionuclide *i* in μCi or Bq as reported by the bioassay for a 24-hr sampling period as applicable

$IRF_i(t)$ = Intake Retention Fraction corresponding to the type of measurement for time *t* after the estimated time of intake as determined in Step 4.2.5

Caution: Ensure the total activity $A_{i\text{-}Bio}$ is decay corrected to the time of bioassay as applicable since the actual sample analysis may occur several days or weeks following sampling.

Caution: The IRF values as provided in Reference 2.8 incorporate radiological decay between the time of intake and bioassay; however, if another reference is used to document the IRF (such as Reference 2.15), an additional radiological decay factor may be needed. If the IRF is based on stable elements; tabulated IRF must be multiplied by a factor of $e^{-\lambda t}$ to account for radiological decay.

4.2.12. Determine the intake from all other radionuclides as applicable that were not detected in the bioassay measurement by inferring or scaling their activities based upon the radionuclide distribution and their ratio to the measured radionuclide at the time of intake.

4.3 Multiple Acute Intakes

4.3.1. Complete the Dose Assessment, Attachment 5.2 or equivalent.

4.3.2. Record the individual's name and personal information as required.

4.3.3. Record the date and time that the bioassay was obtained (i.e., completed).

4.3.4. Record the best estimate of the dates and times of each intake. The dates and times may be estimated using available information including RWP access logs, DAC-hour tracking logs, estimates based upon the recollection of activities, the individual's work schedule, air sampling data or operational history.

4.3.5. Calculate and record the time, *t*, in days between the estimated time of each event or intake and the time that the bioassay was obtained.

4.3.6. Record the radionuclide(s) of concern including all radionuclides based upon process knowledge or air sampling data. Include those radionuclides that were detected through bioassay as well as those that can be inferred based upon the radionuclide distribution and process knowledge.

4.3.7. Enter the inhalation class of the radionuclide(s) of concern based upon the chemical form as specified by the PHP/CHP and/or CS RSO. If the chemical form or inhalation class is not known, use the most restrictive class for the radionuclide.

4.3.8. Enter the total activity, $A_{i\text{-}Bio}$, from the whole body count or the bioassay sample measurement.

4.3.8.1. For urine samples reported in μCi/ml or pCi/ml, multiply the reported result by the actual 24-hr void volume or the "reference man" daily void (1,400 ml per day for men or 1,000 ml per day for women).

4.3.8.2. For fecal samples reported in μCi/g or pCi/g, multiply the reported results by the actual 24-hr weight of excretion, or the "reference man" daily excretion weight (135 g per day for men or 100 g per day for women).

4.3.9. Determine the fractional distribution of intake for each acute exposure using DAC-hr tracking (or other assumptions based upon events). The sum of the fractions will add up to 1.

4.3.10. The activity that appears in the bioassay from multiple acute intakes is assumed to follow the following equation.

$$A_{i-Bio} = I_{total} \cdot \sum f_i(t) \cdot IRF_i(t)$$

Where:
- $A_{i\text{-}Bio}$ = Total activity for radionuclide *i* in μCi or Bq as reported by the bioassay for a 24-hr sampling period as applicable
- I_{total} = Total intake in μCi or Bq
- $f_i(t)$ = Fraction of intake for radionuclide *i* for each event at time *t* prior to bioassay
- $IRF_i(t)$ = Intake Retention Fraction corresponding to the type of measurement at the specified time *t* of each intake as determined in Step 4.3.5

4.3.11. Determine the total intake by re-arranging the prior equation as follows.

$$I_{total} = \frac{A_{i-Bio}}{\sum f_i(t) \cdot IRF_i(t)}$$

4.3.12. Record the total intake, I_{total}, on Attachment 5.2 or equivalent.

4.3.13. After calculating the intake for each radionuclide as measured in the bioassay, estimate the intake of any other radionuclides by inferring the calculated intake from the fractional distribution of radionuclides in the workplace air samples or as determined by process knowledge.

4.4 Continuous Intake

4.4.1. Complete the Dose Assessment, Attachment 5.3 or equivalent.

4.4.2. Record the individual's name and personal information as required.

4.4.3. Record the date and time that the bioassay was obtained (i.e., completed).

4.4.4. Record the monitoring period of the exposure *T* based upon the time of the prior bioassay sample, RWP access logs, DAC-hr tracking, estimates based on the recollection of activities, the individual's work schedule, air sampling data or operational history.

4.4.5. Record the time *t* from the start of exposure to the time of bioassay sampling.

4.4.6. Record the radionuclide(s) of concern including all radionuclides based upon operational knowledge and air sampling data. Include those radionuclides that were detected through bioassay as well as those that can be inferred based upon the radionuclide distribution and process knowledge.

4.4.7. Enter the inhalation class of the radionuclide(s) of concern based upon the chemical form as specified by the PHP/CHP and/or CS RSO. If the chemical form or inhalation class is not known, use the most restrictive class for the radionuclides.

4.4.8. Enter the total activity, $A_{i\text{-}Bio}$, from the whole body count or the bioassay sample measurement.

4.4.8.1. For urine samples reported in μCi/ml or pCi/ml, multiply the reported result by the actual 24-hr void volume or the "reference man" daily void (1,400 ml per day for men or 1,000 ml per day for women).

4.4.8.2. For fecal samples reported in μCi/g or pCi/g, multiply the reported results by the actual 24-hr weight of excretion, or the "reference man" daily excretion weight (135 g per day for men or 100 g per day for women).

4.4.9. For continuous intake that occurs during an assumed period of time *T*, Section 4.4 of Reference 2.5, US NRC Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program, Revision 1, 1993*, provides a model that assumes the intakes are distributed equally in size and time and may be approximated using a relationship based upon time integration of the IRF using the following equation.

$$I_{total} \approx \frac{A_{i-Bio} \cdot n}{\left(\frac{IRF_i(t-T) + IRF_i(t)}{2} \right) + \sum_{n=1}^{T-1} IRF_i(t-n)}$$

Where:
- I_{total} = Total intake in μCi or Bq
- $A_{i\text{-}Bio}$ = Total activity for radionuclide *i* in μCi or Bq as reported by the bioassay for a 24-hr sampling period as applicable
- T = Duration of intake in days
- t = Time from onset of intake to the time of bioassay sampling as determined in Step 4.4.5 in days
- IRF_i = Intake Retention Fraction corresponding to the type of measurement at the specified time
- n = Number of increments in days

Note: With spreadsheets it is easy to do the continuous intake using an increment of 1 day. Generate a table of IRF values with 1 day increments, interpolating between values greater than 1 day.

4.4.10. Record the total intake, I_{total}, on Attachment 5.3 or equivalent.

4.4.11. After calculating the intake for each radionuclide as measured in the bioassay, estimate the intake of any other radionuclides by inferring the calculated intake from the fractional distribution of radionuclides in the workplace air samples or as determined by process knowledge.

4.5 Prior Exposure Contribution

For instances were a prior exposure may impact the bioassay results, the contribution of the prior exposure shall be determined.

4.5.1. From the prior Bioassay result, use the single acute intake exposure model, Section 4.2, and the prior bioassay result to determine any potential contribution to the current bioassay.

4.5.2. Subtract the prior exposure contribution from the current bioassay result.

4.5.3. Follow the applicable exposure model for the current monitoring period using Sections 4.2, 4.3 or 4.4 as applicable to perform the dose assessment.

4.6 Committed Effective Dose Equivalent

4.6.1. The method for calculating the estimated internal dose to the individual detailed in the following is to use Dose Conversion Factors (*DCFs*) as provided in Reference 2.14, EPA 520/1-88-020 (Federal Guidance Report

No. 11), *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*.

Note: Alternate methods may also be used such as provided in Reference 2.6, US NRC Regulatory Guide 8.34, *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses, July 1992.*

4.6.2. Determine the *DCFs* from Reference 2.14 for each radionuclide of concern as applicable and document them on the appropriate dose assessment form, Attachments 5.1, 5.2, 5.3 or equivalent. Calculate and record the Committed Effective Dose Equivalent (*CEDE*) for each radionuclide *i* as follows:

$$CEDE_i = I_i \times DCF_i \times 3.7\,E6$$

Where: I_i = Estimated total intake of radionuclide *i* in μCi

DCF_i = Dose conversion factor per unit intake for radionuclide *i* from Federal Guidance Report 11 for intake by inhalation or ingestion in units of Sv/Bq

3.7E6 = Conversion factor for Sv/Bq to rem/μCi

4.6.3. Calculate and record the total *CEDE* from all applicable radionuclides of concern as follows:

$$CEDE = \sum CEDE_i$$

4.7 Committed Dose Equivalent, CDE

4.7.1. Organ or tissue specific Committed Dose Equivalent(s) (*CDEs*) shall be calculated when the radionuclide is limited by a non-stochastic ALI to a specific organ.

Note: According to 10CFR20 Appendix B, Table 2; when an ALI is defined by the stochastic dose limit, this value alone, is given. When an ALI is determined by the non-stochastic dose limit to an organ, the organ or tissue to which the limit applies is shown, and the ALI for the stochastic limit is shown in parentheses; (LLI wall = lower large intestine wall; St. wall = stomach wall; Blad wall = bladder wall; and Bone surf = bone surface).

4.7.2. Determine the *DCFs* for organ *T* for each radionuclide of concern as applicable from Reference 2.14 and document them on the appropriate dose assessment form, Attachments 5.1 or 5.2 or equivalent. Calculate and record the CDE_T for the organ *T* as follows:

$$CDE_T = \sum I_i \times DCF_{Ti} \times 3.7\,E6$$

Where: CDE_T = CDE for organ *T* in rem

I_i = Estimated total intake of radionuclide *i* in μCi

DCF_i = Dose conversion factor per unit intake for radionuclide *i* and organ *T* from Federal Guidance Report 11 for intake by inhalation or ingestion in units of Sv/Bq

3.7E6 = Conversion factor for Sv/Bq to rem/μCi

4.8 Review and Approval

4.8.1. Sign and date the applicable Dose Assessment, Attachments 5.1, 5.2, 5.3 or equivalent.

4.8.2. Attach copies of any bioassay monitoring results used in the calculations of the report.

4.8.3. Submit the completed Dose Assessment to the CS RSO for review and approval.

4.8.4. If the CEDE for the initial dose assessment exceeds 100 mrem, an independent review should be performed for adequacy of the bioassay measurements and monitoring program and follow-up bioassays performed in accordance with Section 4.9 as directed by the PHP/CHP.

4.8.5. If the CEDE and CDE are less than 10% of the annual limits, a follow-up assessment is not required.

4.8.6. If follow-up bioassay monitoring is required, revise and refine the internal dose assessment in accordance with Section 4.10

4.8.7. If the CEDE or CDE are confirmed to be greater than 10% of the annual limits, and the dose is not consistent with the expected pattern of exposure, an investigation should be performed to confirm the intake in accordance with Section 4.12.

4.9 Follow-Up Bioassay Measurements

4.9.1. Follow-up bioassay monitoring may be required as directed by the PHP/CHP to track the elimination of the radionuclides from the body and to provide modified or revised dose assessments as necessary.

4.9.2. The frequency of follow-up bioassay measurements will be determined by the PHP and a Certified Health Physicist.

4.9.3. The biological or effective half-life may be determined either by whole body count or sample collection and analysis depending upon the radionuclide(s) of concern and their detection sensitivities.

4.9.4. Establish follow-up bioassay monitoring and sample frequencies following the guidance of the PHP/CHP. The following Table, Table 4-1, may be used as guidance based upon the suspected biological half life of the radionuclide(s) of concern.

Table 4-1

Follow-up Bioassay Monitoring Frequencies

T_{eff} [a]	Frequency
1 – 7 days	daily to weekly
1 – 2 weeks	weekly to bi-weekly
>2 weeks	bi-weekly to monthly

a Effective or biological ½ life in days

4.10 Refining the Intake

4.10.1. US NRC Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program, Revision 1, 1993*, Reference 2.5 and ANSI HPS N13.39 recommend that additional measurements be obtained if the CEDE or CDE are confirmed to be greater than 10% of the annual limits, and the dose is not consistent with the expected pattern of exposure such as determined by DAC-hr tracking. The investigation should include:

4.10.1.1. Refining the actual exposure conditions of the intake, as opposed to using default assumption, to the extent possible.

4.10.1.2. Obtaining special bioassay data unless it is technically infeasible because of a technology shortfall or the radionuclide has a short effective half-life.

4.10.1.3. Notifying the worker that an investigation is being performed.

4.10.1.4. Restricting radiation work temporarily if additional exposure could interfere with the investigation.

4.10.2. Re-perform the dose assessment using any follow-up bioassay data to verify initial assumptions and to verify any Intake Retention Fractions.

4.10.3. Refine the models, methods, and information as available following the guidance of a CHP.

4.10.4. If several bioassay measurements have been performed over a period of time, an estimate of the intake may be obtained using one of the methods described in Reference 2.5, US NRC Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program, Revision 1, 1993*, or Reference 2.8, NUREG/CR-4884, *Interpretation of Bioassay Measurements, 1988*.

4.10.5. Revise the personnel's Intake and document the new dose assessment.

4.10.6. Submit the revised assessment to the RSO for review and approval.

4.11 Exposure Records

4.11.1. Once the assessment has been approved, the assessment shall be placed in the personnel record with all supporting documentation including all information needed to complete the NRC Form 5 or equivalent.

4.11.2. Complete or revise the individuals NRC Form 5 in accordance with Reference 2.18, CS-RS-PR-010, *Personnel Monitoring for Exposure – Internal and External* as necessary.

4.12 Internal Exposure Investigation

4.12.1. The RSO will direct when an exposure investigation is required. Generally intakes less than 0.1 ALI will not require investigation. The commercial services administrative dose limits in Reference 2.16, CS-RS-PG-001, *Radiation Protection Program Commercial Services Projects*, are 2 rem TEDE, and 20 rem (total organ dose equivalent).

4.12.2. The investigation of an unexpected/unplanned positive bioassay is performed to determine the cause of the intake. The investigation is documented using Attachment 5.4, Internal Exposure Investigation Report, or equivalent.

4.12.3. Once the cause of the intake has been determined, the remaining actions may be marked "Not applicable."

4.12.4. The following actions should be performed when investigating a positive bioassay.

4.12.4.1. Interview the affected individual(s), attempt to determine where the intake occurred, what work was being performed and if any other individuals were involved. If other individuals were involved in the same work activity, they should have a bioassay performed.

4.12.4.2. Interview Health Physics personnel, who provided work coverage (if applicable), and determine if work methods may have been the cause of the intake.

4.12.4.3. Review the radiation work permit and survey data to determine what radiological controls were imposed while work was being performed.

4.12.4.4. Consider having additional surveys performed in the affected work area to determine if radiological conditions might have changed.

4.12.4.5. Review additional bioassay data, collected in accordance with Section 4.9, to monitor the elimination of the radionuclides from the body of the affected individual(s).

4.12.4.6. Impose work restrictions for affected individual(s).

4.12.5. If the investigation shows that either poor radiological work practices or a previously unidentified radioactive source was the cause of the intake, provide recommendations for corrective action and submit to the RSO for review and approval.

5.0 ATTACHMENTS AND FORMS

5.1 Dose Assessment – Single Acute Intake

5.2 Dose Assessment - Multiple Acute Intakes

5.3 Dose Assessment - Continuous Intake

5.4 Internal Exposure Investigation Report

(Attachment 5.1) Dose Assessment - Single Acute Intake

Name:	**SSN:**
Intake Pathway [a]:	**Bioassay Type:**
Intake Date and Time:	**Bioassay Date and Time:**
Delta Time t (Days) [b]:	**Estimated DAC-hrs:**

a Intake Pathway is typically Inhalation.
b Delta time is the time between the event and the time of bioassay collection.

Nuclide	Nuclide Class (D / W / Y)	Activity [a] $A_{i\text{-}Bio}$ (uCi)	Retention Fraction [b] IRF_i (t)	Intake [c] I_i (uCi)	Dose Conv. Factor [d]		Dose [e]	
					WB DCF_i (Sv / Bq)	Organ DCF_i (Sv / Bq)	WB $CEDE_i$ (rem)	Organ CDE_i (rem)
TOTAL								

a Total activity based upon the bioassay sampling results.
b Intake Retention Fraction at time t in days from the exposure event to the time of bioassay.
c Total intake of the initial exposure or event. Determined by dividing the bioassay activity $A_{i\text{-}Bio}$ by $IRF_i(t)$ to get I_i.
d Dose conversion factor in Sv / Bq either for the effective whole body dose or the organ dose.
e Reported Dose in rem; Whole Body (WB) or Organ as determined by multiplying $A_{i\text{-}Bio}$ by DCF_i and a conversion factor of 3.7E6 rem / μCi per Sv / Bq.

Completed by:	**Date:**
Reviewed by:	**Date:**

(Attachment 5.2) Dose Assessment - Multiple Acute Intakes

Name:			SSN:		
Intake Pathway [a]:		Bioassay Type:		Date and Time:	
Intake / Event	**1**	**2**	**3**	**4**	**5**
Intake Date and Time:					
Delta Time t (Days) [b]:					
Estimated DAC-hrs:					

a Intake Pathway is typically Inhalation.
b Delta time is the time between each specific event and the time of bioassay collection.

Nuclide	Nuclide Class (D / W / Y)	Event	Retention Fraction [a] IRF_i (t)	Intake Fraction [b] f_i	Retained Fraction [c] f_i*IRF_i (t)	Activity [d] $A_{i\text{-}Bio}$ (uCi)	Intake [e] I_i (uCi)	Dose Conv. Factor [f] WB DCF_i (Sv / Bq)	Dose Conv. Factor [f] Organ DCF_i (Sv / Bq)	Dose [g] WB DCF_i (rem)	Dose [g] Organ DCF_i (rem)
		1									
		2									
		3									
		4									
		5									
TOTAL				1.0	Σ =						

a Intake Retention Fraction at time t in days for each specific exposure event to the time of bioassay.
b Intake fraction of the total intake attributed to that event. May be estimated by the fraction of the total DAC-hrs or the number of hours attributed to that event.
c Retained fraction of the entire intake attributed to that event. Determined by multiplying the fraction, f_i, by the $IRF_i(t)$.
d Total activity based upon the bioassay sampling results.
e Total cumulative intake. Determined by dividing the bioassay activity $A_{i\text{-}Bio}$ by the sum Σ [f_i times $IRF_i(t)$] to get I_i.
f Dose conversion factor in Sv / Bq either for the effective whole body dose or the organ dose.
g Reported Dose in rem; Whole Body (WB) or Organ as determined by multiplying $A_{i\text{-}Bio}$ by DCF_i and a conversion factor of 3.7E6 rem / μCi per Sv / Bq.

Completed by:	Date:
Reviewed by:	Date:

(Attachment 5.3) Dose Assessment - Continuous Intake

Name:			SSN:		
Intake Pathway [a]:		Bioassay Type:		Date:	
First Exposure Date:		Last Exposure Date:		Days of Exposure:	
Intake Interval (Day)	**1**	**2**	**3**	**4**	**5**
Interval Date:					
Delta Time t (Days) [b]:					

a Intake Pathway is typically Inhalation.
b Delta time is the time between the event and the time of bioassay collection

Nuclide	Nuclide Class (D / W / Y)	Interval (Days)	Retention Fraction [a] IRF_i (t)	Retention Fraction [b] IRF_i (t)	Activity [c] $A_{i\text{-}Bio}$ (uCi)	Intake [d] I_i (uCi)	Dose Conv. Factor [e] WB DCF_i (Sv / Bq)	Dose Conv. Factor [e] Organ DCF_i (Sv / Bq)	Dose [f] WB DCF_i (rem)	Dose [f] Organ DCF_i (rem)
		1st								
		Last								
		2nd								
		3rd								
		4th								
TOTAL		n =		Σ =						

a Intake Retention Fraction at time t in days for each exposure interval to the time of bioassay.
b Carry over the Intake Retention Fraction for each interval with the exception of the 1st and last which is carried over as the average of the two.
c Total activity based upon the bioassay sampling results.
d Total cumulative intake. Determined by multiplying the bioassay activity $A_{i\text{-}Bio}$ by the total number of exposure intervals, n, and dividing by the sum Σ [IRF_i (t) + $IRF_{i\text{-}avg}$ (first and last)]
e Dose conversion factor in Sv/Bq either for the effective whole body dose or the organ dose
f Reported Dose in rem; Whole Body (WB) or Organ as determined by multiplying $A_{i\text{-}Bio}$ by DCF_i and a conversion factor of 3.7E6 rem / μCi per Sv / Bq.

Completed by:	Date:
Reviewed by:	Date:

(Attachment 5.4) Internal Exposure Investigation Report

Last Name:	**First Name:**
SSN:	**RWP:**
Date and Time of Event:	**Estimated CEDE:**
Summary of Events:	
Interview / Investigation Results:	
Root Causes:	
Recommendations:	
Review and Approval	
Performed by:	**Signature/Date:**
Reviewed by:	**Signature/Date:**